RISK BASED ANALYSIS IN FLOOD DAMAGE REDUCTION STUDIES

by

Earl E. Eiker, P.E.[1]

INTRODUCTION

The concepts of Risk Based Analysis (RBA) are not new. Evaluation of risk and accommodation of uncertainty have been important considerations in the development of flood damage reduction projects since the Corps became involved in the 1920's. The concepts of risk and risk reduction form the very foundation of the Corps flood damage reduction program. Furthermore, the formal consideration of risk in project formulation studies has been required by the Planning Guidance Notebook (ER 1105-2-100) since it was first published in the early 1980's.

Until recently there was no systematic procedure to account for risk. The development and use of RBA in flood damage reduction project formulation studies has permitted more informed decisions because much more detailed information on project economics and project performance is now available to the decision maker. For the first time, we have a method that enables us to explicitly and analytically integrate risk and data uncertainty directly into the analysis. In spite of the power of the RBA methodology, it should still be thought of as simply one tool in the toolbox. In the formulation and design of a flood damage reduction project, RBA is only one part of the total study effort.

Finally, with the trend in the Federal government toward use RBA methods as the bases for investment decisions, the Office of Management and Budget (OMB) has encouraged and supported the Corps in the development of this technology. Thus, the continued use and improvement of RBA is critical to the Corps in maintaining a viable flood damage reduction program.

HISTORY OF RBA IN THE CORPS

Corps involvement with RBA began in the early 1980's with an attempt to develop a RBA procedure to evaluate hydrologic deficiencies at Corps reservoir projects, as part of its Dam Safety Assurance Program. These efforts, while unsuccessful in establishing a comprehensive RBA method, did result in a quasi-risk based method of evaluation, known as incremental hazard analysis, that was published in a 1985 Corps Policy Letter. Today the same guidance is contained in ER 1110-2-1155. This method of analysis is presently used by all Federal dam building agencies to evaluate hydrologic deficiencies.

---

[1] Ch., Hydraulics and Hydrology Br., HQ, U.S. Army Corps of Engineers

During the early 1990's, a RBA method was developed to allow uniform evaluation and prioritization of projects proposed for remedial work under the Corps Major Rehabilitation Program. Implementation guidance was published in 1993.

In the area of flood damage reduction, development of the current RBA method began with a workshop on riverine levee freeboard, held in Minneapolis, MN, in August 1991. At this workshop the basic approach to RBA for flood damage reduction project formulation was presented and discussed. Following the workshop, efforts to fully develop the method were undertaken and the first Corps guidance on application was published as EC 1105-2-205 in 1993. During 1993 and 1994 a series of five workshops were conducted throughout the country to introduce Corps field offices to the emerging technology. At the same time, coordination of the RBA method was undertaken with the Federal Emergency Management Agency (FEMA) and the Association of State Floodplain Managers (ASFPM), both of whom expressed some reservations relative to the application of RBA, particularly with respect to Corps levee certification. In order to provide for an independent technical review, the National Research Council (NRC), as part of a Congressionally mandated review of the American River project, was asked by the Corps to evaluate the RBA procedure used in the formulation studies for this project. The final NRC report raised some technical issues, but in general supported the RBA approach. The ASFPM still had some concerns with widespread use of RBA and as a result of these concerns, Congress directed the Corps, in WRDA '96, to again seek an independent review by the NRC, that would be more general in scope than the previous review that addressed only the American River application. This review, which the Corps expects will result in a positive conclusion, will begin in 1998 and take about two years to complete. In the meantime the Corps remains committed to RBA and will continue to use RBA in flood damage reduction studies. Current policy guidance on application of RBA to flood damage reduction studies is contained in ER 1105-2-101, while engineering guidance is contained in EM 1110-2-1619.

Ongoing efforts in the development of RBA procedures for additional applications are focused on navigation, both deep and shallow draft, and coastal engineering.

OVERVIEW OF RBA FOR FLOOD DAMAGE REDUCTION STUDIES

The development of the current RBA methodology has been a true Corps-wide effort. It has been interdisciplinary (engineering and economics), inter-laboratory (HEC, IWR and WES) and has had the benefit of field office application. In addition, RBA has been extensively coordinated with other Federal agencies and non-governmental organizations.

Formulation and Design Objectives. Flood damage reduction projects are formulated to provide safe, efficient and effective protection to lives and properties in flood prone areas. Projects are formulated by analyzing flood plain damage potential, and damage prevention performance and cost for a range of project sizes and configurations. The plan selected is based on maximizing net economic benefits consistent with acceptable risk and functional performance.

The engineering challenge is to balance risk of design exceedance with flood damage prevented, uncertainty of flood levels with design accommodations, and provide for safe and predictable performance. The task is made difficult because economics dictate that less than complete protection be accepted, risk of capacity exceedance is real and must be planned for because it may occur within the life of the project, and uncertainty in flood levels exists because of imperfect knowledge.

Uncertainty in the Analysis. Planning flood damage reduction projects requires information on discharge/frequency, stage/discharge, and stage/damage relationships at points along the stream where protection is to be provided. Such information is obtained from observed and measured data, or is estimated by various synthetic procedures and modeling techniques. The information is frequently based on short records and small sample sizes, and subject to measurement errors and inherent limitations and assumptions associated with the analytical techniques employed. These estimated values are, to various degrees, imprecise or inaccurate and thus induce uncertainty in key variables and decision making parameters.

Risk-Based Analysis Approach (ref. 1). RBA is a method of performing studies in which uncertainty in technical data is explicitly taken into account. With such analyses, trade-offs between alternatives, risk, and consequences are made highly visible and quantified. The overall effect of risk and uncertainty on project design and economic viability can be examined and conscious decisions made reflecting an explicit tradeoff between risk and costs.

The RBA approach has many similarities with traditional practice in that the basic data are the same and best estimates are made of discharge/frequency curves, stage/discharge curves (water surface profiles), and stage/damage relationships. The difference between the traditional approach and the risk-based approach is that uncertainty in technical data is quantified and explicitly included in evaluating project performance and benefits. Using RBA, performance can be stated in terms of the probability of achieving stated goals. Also, surrogates in the form of adjustments or additions to design features (e.g. freeboard on levees to account for hydraulic uncertainties) to specifically accommodate uncertainty are not necessary.

RBA quantifies the uncertainty in discharge/frequency, stage/discharge, and stage/damage relationships and explicitly incorporates this information into economic and performance analyses of alternatives. The process requires a statistical sampling analysis method to compute the expected value of damage and damage reduced, while explicitly accounting for uncertainty.

The method used to develop the discharge/frequency relationships depends on data availability. For gaged locations and where an analytical determination is appropriate, uncertainties for discrete probabilities are represented by the non-central *t* distribution (ref. 2). For ungaged locations, the discharge/frequency function may be adopted from applying a variety of approaches (ref. 3). When justified, curve fit statistics for the adopted function are computed. An equivalent record length is assigned based on the analysis and judgements about the quality of information used in adopting the function. Regulated (e.g. by a flood control dam) discharge/frequency, stage/frequency and other non-analytical probability functions require different methods. An approach referred to as "order statistics" (ref. 3) is applied to develop the probability function and associated uncertainty for these situations.

Stage/discharge functions are developed for index locations from measured data at gages or from computed water surface profiles. For gaged data, uncertainty is calculated from the deviations of observations from the best fit rating curve. Computed profiles are required for ungaged locations and for proposed project conditions that are modified from that of historic observations. Where sufficient historic data exists, water surface profile uncertainty is estimated based on the quality of the computation model calibration to the historic data. Where data are scant, or the hydraulics of flow complex, such as for high velocity flow, debris and ice jams, and flow bulked by entrained sediments, special analysis methods are needed. One approach is to perform sensitivity analysis of reasonable upper and lower bound profiles and use the results to estimate the range of the uncertainty in stage.

Stage/damage functions are derived from inventory information about structures, structure content and other damageable property located in the flood plain. The functions are constructed at damage reach index locations where discharge/frequency and stage/discharge functions are also derived. Presently, separate uncertainty distributions for structure elevation, structure value, and content values are specified and used in a Monte Carlo analysis to develop the aggregated structure stage/damage function and associated uncertainty. The uncertainty is represented as a standard deviation of error at each stage coordinate used for defining the aggregated function at the index location.

In the development of the best estimates and the error distributions for the three primary parameters discussed above, a "common sense approach" should be taken. That is to say, most of the study effort should be devoted to the parameter (or parameters) that will most affect the final recommendation. For example, the frequency curve will generally have the largest impact on the study results, but, if the study area has a broad, flat floodplain, a relatively small increase in water surface elevation can have a major effect on both discharge and damage estimates, and thus should be studied in greater detail. The total amount of effort to needed to adequately define these parameters should be based on the type of study (e.g. recon, feasibility, etc.), and the size and complexity of the project.

The basic steps to carry out the RBA are:

a. Develop best estimates of discharge/frequency curves, water surface profiles (stage/discharge ratings), and stage/damage relationships for the without project conditions.

b. Develop statistical descriptions of uncertainty for each of the above relationships.

c. Nominate alternative project capacities; compute costs and flood damage prevented; array results and select a plan according to appropriate economic criteria.

Parameter estimates for the with project conditions used, in step c above, are developed by modifying the appropriate without project parameters. For a reservoir or diversion project, the frequency curve would be modified to reflect the effects of storage or diversion on flows in the damage reaches. For a channel or levee project the rating curve in the damage reach would be modified to reflect greater channel capacity. For a non-structural project the depth/damage curve would be modified.

The above steps are repeated as needed for each alternate measure evaluation, or combinations of measures to enable comparison of project alternatives. Step c brings together all the elements to determine the selected project capacity. To correctly incorporate uncertainty in the several elements, they must be allowed to interact with one another. For example, the possibility of error for higher flows (or lower flows) of a specific probability flood must be allowed to couple with the full range of possible stage and damage errors. Because of the nature and complexity of the error distributions, the interaction cannot be uniquely accomplished analytically. An alternative approach is to use Monte Carlo simulation. In this approach, the basic relationships and error distributions are sampled by exhaustive trial to allow the interaction to take place. For a given size or type of project, various combinations of the primary parameters are evaluated and for each interaction success or failure is established. Other project sizes and/or types are evaluated, and a matrix describing economic outputs and performance for each is produced. The matrix forms the basis for initial project selection.

The results of the analyses are probability distributions of the various parameters (flow, stage, and residual damage) as a function of project capacity. The expected cost and benefit for each alternative are computed and the most economical project capacity selected according the appropriate criteria. Tabulations of the likelihood of project capacity exceedance for flood events are produced that enable characterization of risk exceedance and performance. The RBA method quantifies the performance of project design. This performance is reported as the protection for a target percent chance exceedance flood with a specified annual non exceedance probability. For example, the proposed project is expected to provide protection against the one-half percent (0.5%) chance exceedance flood, should it occur, with a ninety percent (90%) chance of non exceedance. This performance may also be described in terms of the percent chance of controlling a specific historic flood to non-damaging levels.

The first applications of RBA were conducted using a spread sheet program to perform the evaluation. Recently HEC has developed a more user friendly flood damage assessment computer program that has greatly facilitated the application of the RBA procedure.

Summary of RBA. Imperfect knowledge of the "true" nature of the hydrology and hydraulics in an area creates uncertainty in project designs and in the estimate of their expected performance. Additionally, uncertainties in expected damage with and without the project can greatly influence the selection of an alternative plan for design. RBA procedures provide an approach to explicitly quantify the uncertainties associated with discharge/frequency, stage/discharge and stage/damage relationships that are required in the formulation of flood damage reduction projects. The method uses the same basic data as that used in traditional practice, but has the distinct advantage of providing considerable information regarding expected project performance for a broad range of hydrologic conditions. Goals and objectives of project studies are enhanced due to the ability to consider a much wider range of project alternatives.

Initial Applications of RBA. RBA studies conducted to date have been very promising (ref. 4) and feedback from field offices has been positive. In several instances the basic framework has been modified to account for unique circumstances such as the effects of upstream levee breaks and the impact of tidal fluctuations on frequency relationships.

Development of Additional Capabilities. Current research and development efforts are aimed at developing improved geotechnical capabilities and new methods for evaluation of project cost uncertainties for inclusion in the RBA procedure.

OTHER RISK RELATED CONSIDERATIONS

Risk Based Analysis is only one component of a much larger process in a flood damage reduction study. While RBA provides the engineer with a wealth of information that was not previously available, it is not a substitute for good engineering practice, nor is it intended to be. The RBA discussed in this paper is used to formulate the type and size of the optimal structural (or non-structural) plan that will meet the study objectives. Corps policy requires that this plan be identified in every flood damage reduction study it conducts. This plan, referred to as the National Economic Development Plan (NED), is the one that maximizes the net economic benefits of all the alternatives evaluated. It may or may not be the recommended plan based on additional considerations.

The first step in a flood damage reduction study is to conduct the RBA. The RBA identifies the NED Plan and provides a starting point for the design process. As discussed previously, output from the RBA includes data on stage exceedence probabilities and expected project performance at index locations along the stream.

A residual risk analysis for the NED Plan is next performed to determine the consequences of a design exceedence. We know that for a flood damage reduction project, the question is not **IF** the design will be exceeded, but what are the impacts **WHEN** that design is exceeded, in terms of both economics and the threat to human life! If the project induced and/or residual risk is unacceptable, and a design to reduce the risk cannot be developed, other alternatives must be further analyzed. Either a larger project, that will assure sufficient time for evacuation, or a different type of project, with less residual risk, should be studied to reduce the threat to life and property.

When the type and size of the project have been selected, we are ready to begin the detailed design. To attain the confidence that the outputs envisioned in the formulation of the selected project will be realized, specific design requirements are developed. For a levee, increments of height to provide for settlement and consolidation, allow for construction tolerances, and permit the building of a road along the crown for maintenance and access during flood fights are calculated. For a channel project, superelevation, if required to contain the design water surface profile, is determined. For a reservoir, allowances to accommodate the Inflow Design Flood without endangering the structure and to account for wind and wave action are estimated. A similar thought process is also used for upstream diversion projects. These specific requirements must be included in the design.

The design must also include measures to minimize the adverse impacts of a design exceedence. For levees, the final grade is set so that initial overtopping will occur at the least hazardous location along the line of protection. This location is usually at the downstream end of the levee, so the protected area will fill in a gradual manner. This same approach is taken in the final design of channel projects. For reservoirs, the Water Control Plan is developed so that as the point of design exceedence is approached, there is a gradual increase in outflow from the project to provide time to initiate emergency measures downstream. Upstream diversions are also configured (or operated) to allow a gradual increase in flow during a design exceedence. These design efforts notwithstanding, it is normal practice to include a flood warning system in the final plan as a last measure for risk reduction.

Design of a flood damage reduction project places a special responsibility on the design engineer because of the potentially catastrophic consequences of a design exceedence. Of the types of structural projects usually considered in a flood damage reduction study, a levee is by far the most dangerous due to the severe consequences that may result from overtopping. If a levee cannot be designed to assure gradual filling of the protected area when the design is exceeded, then it simply should not be built. Reservoirs, channels and upstream diversions are better structural choices than levees from a hazard perspective. They provide some measure of protection even after their design is exceeded, and, they are better suited to minimize the adverse impacts of a design exceedence because they can be designed and/or operated to effect a gradual increase in flows and inundation in the protected areas.

CONCLUSION

The Corps is committed to the use of RBA in all flood damage reduction studies. RBA has greatly improved our ability to formulate quality projects through the production of additional economic and performance data not previously available. As we continue to expand our capabilities by the addition of procedures to address geotechnical and cost uncertainties, RBA will become an even more powerful tool. When RBA is coupled with sound engineering practice, the best project from a public safety and hazard reduction standpoint results.

REFERENCES

1. Tseng, Ming T., Eiker, Earl E., and Davis, Darryl W., 1993, Risk and Uncertainty in Flood Damage Reduction Project Design, ASCE Conference Proceedings, San Francisco, CA.
2. U.S. Department of the Interior, Geological Survey, 1982, Guidelines for Determining Flood Flow Frequency, Bulletin 17B, Washington, DC.
3. U.S. Army Corps of Engineers, 1996, Risk Based Analysis for Flood Damage Reduction Studies, Engineer Manual 1110-2-1619, Washington, DC.
4. Eiker, Earl E., and Davis, Darryl W., 1996, Risk-Based Analysis for Corps Flood Project Studies- A Status Report, Rivertech '96 Conference Proceedings, Chicago, IL.